Geoecological Risk Management for Stable Development of Gas Industry

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Introduction

Currently, the gas industry is focused on sustainable medium and long-term development, which reveals the particular relevance of environmental security issues especially in the course of developing prospective gas production areas of the Far North, the equatorial zone and the marine shelf. Management of environmental risks, caused by natural gas production, transportation and processing, requires the development of methods for their identification, analysis and adequate quantitative assessment. At the same time it is necessary to take into account the complex nature of interaction between gas industry facilities and environment, landscape and climate and the possibility of “non-economical” consequences of man-caused impact, the scope of which complicates their costs estimation.

The most successful solution of these problems is provided by risk assessment aimed at establishment of qualitative cause-effect relations between the intensity of economic activities and “response effects” of the environment. For qualitative risk parametrisation, the statistical methods are used that allow to measure the amount of risk as a probability of unfavourable events under the given level of man-caused impacts, as well as estimate type and extent of the resulting damage (Gaudet et al., 2000; Evaluation..., 2004). Damage for ecosystems can be determined, for example, through the identification of areas (sites) with the possible extinction of certain biota species, disbalance of normal conditions, poorer plant products or natural water. Thus, environmental approaches are integrated with the mechanisms of economical substantiation of risk reduction and environmental and long-term production safety (Akimov, 2004; Bashkin, 2005; Bykov, 2007). However, identification of direct qualitative dependencies taking into account the heterogeneous nature of natural ecosystems and multi-factor influence of gas industry facilities is rather problematic due to insufficient study of the functioning pattern of natural-territorial complexes and to the lack of qualitative data on environmental consequences of risk factors (Risk..., 1997; Fairman et al., 1999). In this case the systematic approach is most effective because it enables to decompose the multi-factor interactions into the components that can be described by the relatively simple models (Samsonov et. all, 2007). At the same time the further analysis of the obtained results used for taking strategic decisions to reduce and minimise risks as well as to manage and to monitor them becomes easier.

Theoretical Approaches and Methods

According to the major provisions of System Analysis (Khomyakov, 2006) the complicated systems (including natural ecosystems) that consist of a hierarchy of subsystems have a set of relatively stable states that provide their operating mode and structure in space and time and can be quantitatively described by the set of integrated indicators. Adaptation of ecosystems to external impacts is revealed by the “variations” of integral indicators within the certain limits of average value. Changes in the external environment beyond acceptable impacts lead to “adaptation failure”, the familiar phenomenon from the human biology and physiology that is revealed by disturbances in system structure and functioning and is identified by the changes in integral indicators (Bashkin, Evstafieva, 1993). This shows the discrete nature of response of ecosystems and biota to external impacts. Thus, to ensure stable functioning of natural-territorial complexes and to prevent the risk of unfavourable environmental consequences of economic activity, it is necessary to determine acceptable levels of impacts on ecosystems and their corresponding integral (indicator) parameters.

Just that very principle is used in the methodology of critical loads (UBA, 1996; 2004), that is applied in the Europe to control the intensity of trans-border emission of atmosphere pollutants at the intergovernmental level. According to Nilsson, 1986, the critical load value
(CL) defines the permissible threshold of pollutant inflow to ecosystem, below which no disturbances in its structure and operation occur. Calculation of CL values of ecosystems for man-caused impact effects is conducted with the use of simple balance models that incorporate the migration flows specifying the inflow, neutralisation, immobilisation and removal of man-caused compounds. Since pollutants have different impact on environment components, CL are focused on the effects that occur in ecosystems as a result of the impact of certain pollutants. It allows to use this indicator for estimation of partial risks and comparative analysis of efficiency of activities aimed at multi-factor risk reduction.

Using the CL value as an indicator of the permissible impact, the environmental risk for ecosystems caused by operation of the existing or designed production facility can be calculated as probability of exceeding CL within the zone of impact that leads to the worsening of ecosystems or their components. Thus, the excess of the CL will reflect the ratio between the exposure value (current or predicted pollutant load) and the safe level of impact (the value of CL). The sequence of risk analysis procedures related to the impact of the atmospheric emissions of pollutants on ecosystems includes several stages.

- Identification of recipient exposure to risk based on the analysis of data on the toxicity of pollutants, special features of their migration and transformation in natural environments, depending on climatic conditions of area (or water area), routes of exposure (from the emission source to the recipients).
- Assessment of exposure for groups of recipients in the area of potential impact of industrial facilities on the basis of calculation and spatial visualisation of fields of pollutants fallout with the use of models of their atmospheric dispersion from a point source of emissions.
- Assessment of permissible impact parameters - CL values with respect to certain environmental risks that are revealed in various damages of ecosystems. The results of CL calculations, as a rule, can be visualised in the form of maps or shape files in GIS projects showing the differentiated sustainability of different ecosystems.
- The quantitative risks assessment based on an estimation of the probability of CL excesses in the impact zone for different scenarios of pollutants emissions. Monte-Carlo method (Samsonov et al, 2007; Heywood et al., 2006) is the most frequently used for probabilistic assessments. Since CL is calculated with respect to certain effects, the visualisation of the results of risk assessment (excesses of CL) allows to rank the territory by risk levels and disturbances nature, and to estimate the extent of environmental disbalance, which is necessary for the further monitoring and risk management.
- On the basis of risk assessment data the technological decisions are made along with the development of activities for reducing (minimisation) risks taking into account ecological and economic effectiveness and environmental priorities.

Results and Discussion

The proposed approach was implemented in two gas-producing regions located in contrasting climatic conditions: the territory of Bovanenkovo GCF on the Yamal peninsula and the territory of Venezuela. The impact of eutrophication and acidifying compounds of nitrogen (NO\textsubscript{x}), which are present in the emissions of gas industry production facilities, is considered as a factor of environmental risks. Risk assessments are carried out for the step-by-step scenarios of putting new technological facilities into operation.

The territory of the Yamal peninsula, situated in the Russian zone of the Far North, is characterised by predominance of sub-arctic and tundra ecosystems, which are extremely sensitive to external impact. At the first stage the permissible CL of nitrogen that do not cause soil acidification and terrestrial biocenoses eutrophication leading to replacement of the major types of ground cover were identified for impact zones of the ecosystems. In the Far North conditions the negative consequences of changes in species composition of tundra vegetation are associated with the risk of reducing the share of lichens and mosses in the projective cover, which will cause changes in thermal characteristics of soil and decrease in reindeer forage base productivity during the first years of deposit development. Calculations of CL values were carried out taking into account the features of biogeochemical mass budget of nitrogen and associated macroelements (C, Ca, Mg etc.) in the Far North ecosystems, using the literary data (Productivity., 1976; Archegova, Kotelina, 1979; Bazilevich, 1993; and others).
Obtained results of calculation of acidity CL show the low potential of stability of Bovanenkovo GCF ecosystems with respect to the acid component of atmospheric precipitations. The permissible level of acid-producing compound inflow is estimated at the level of 100-200 e/ha per year or in terms of nitrogen 1,5-3 kg N/ha per year. The calculated values of CL with respect to eutrophication effects are higher and vary from 2-5 to 10 kg N/ha per year according to predominant types of plant communities.

Estimation of Bovanenkovo GCF ecosystems’ exposition caused by emission of nitrogen oxides was carried out on the base of modelling of nitrogen fallout fields generated by the point sources using specially designed model (Report, 2004). Calculated values of nitrogen fallout show the increase of emission intensity when 3 central processing facilities are gradually put into operation. Zone of probable impact corresponds to the radius of 25-50 km; an additional inflow of nitrogen to ecosystems due to natural gas flaring at different emission intensity can reach 0.5-2 to 20-25 kg N/ha per year.

The next work stage was the qualitative assessment of eutrophication and ecosystem acidification risks. It was carried out according to the proposed approach on the basis of probabilistic calculations of CL exceeding using the Monte-Carlo method. Ranking of the obtained risk indicators was carried out according to Table 1.

Table 1. Principles of risk (CL exceeding) classification

<table>
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<tr>
<th>Risk classes</th>
<th>Probability (%)</th>
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<tbody>
<tr>
<td>Almost no risk</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>Low risk level</td>
<td>5 - 25%</td>
</tr>
<tr>
<td>Medium risk level</td>
<td>25 - 75%</td>
</tr>
<tr>
<td>Increased risk level</td>
<td>75 - 95%</td>
</tr>
<tr>
<td>High risk level</td>
<td>&gt; 95%</td>
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As specified in the Table 1 high risk level corresponds to 95% of probability of CL exceeding; if probability of exceeding is 75-95%, the level of risk is increased; when probability is 25-75%, the level of risk is medium. Probability of CL exceeding lower than 25% indicates the low level of risk.

According to our calculations, the maximum parameters of NO\(_X\) emission during the operation of this area of the Bovanenkovo GCF will determine the increased (P = 0.75-0.95) and high (P> 0.95) risk of CL exceeding for ecosystems within the 30-kilometre zone of impact. It will lead to terrain disturbances caused by the loss of the main types of lichens and mosses during the early years of deposit development. In accordance with specialists’ estimates, the oligotrophic species and waste grounds can be gradually replaced by eutrophic grassland vegetation species, especially by cereal plants. Adjustment of nitrogen fallout level due to the insignificant decrease of NO\(_X\) emission will make it possible to cut down the probability of environmental risks for tundra ecosystems to the level of P<0.75 in most of the impact zone.

Calculations of environmental risks for the territory of Venezuela due to the increase in emissions of air pollutants as a result of the scheduled upgrading of the gas industry are made taking into account the integrated impact of emissions of nitrogen oxides from several groups of facilities and locations:

- oil and gas fields;
- operating and designed fuel processing plants;
- designed gas transmission system facilities.

Quantitative assessment of environmental risks in this paper is based on the determination of the proportion (percent) of area of Venezuela, which ecosystem experiences the probability (P) of the risk of exceeding CL of eutrophication or acidification by nitrogen compounds. The calculations are performed with a spatial resolution of 10x10 km.

Calculations of the parameters of volume emissions of nitrogen oxides are made by the standard methodology developed in VNIIGAZ (Methodology., 1996) on the basis of data on the
current and estimated levels of gas flow from all kinds of gas industry facilities in Venezuela. As for point source emissions (gas processing plants), values of volume emissions from several industrial facilities closely located were summarized. As for oil and gas fields, total emissions were calculated as weight mean value of the area of the respective field.

Simulation of nitrogen fallout, as a combined effect of dry deposition and inflow with the atmospheric precipitation, was carried out using the above mentioned model (Report, 2004). Simulation of nitrogen fallout was carried out for each considered gas industry facility by years for a 20-year period. In the case of “superposition” of fallout concentration fields of different facilities, the data were summed up.

The calculated values of CL for eutrophying and acidifying nitrogen compounds reflect the diversity of the natural environment of Venezuela, which is revealed by the differentiated ecosystem stability to pollutant impact (Figure).

![Figure. Shares of Venezuela with different CL of acidity (left graph) and CL of nutrient nitrogen (right graph)](image)

Acidity CL varies from less than 250 to 3000 e/ha per year. For approximately 10% of Venezuela territory the acceptable level of acid impact is estimated at lower than 500 e/ha per year; more than 40% of the country’s area have the high stability potential for acids fallout - 2000 e/ha per year and more. Rather different distribution pattern is typical for CL of nutrient nitrogen. According to the results, the ecosystems of approximately 40% of Venezuela have quite low CL values (nut – less than 500 e/ha per year (or < 7 kg N/ha per year). CL values more than 2000 e/ha per year (i.e. > 20-25 kg N/ha per year) are typical for approximately 30% of territory.

The results of probabilistic evaluation of environmental risks for the main types of ecosystems of Venezuela with no account of emission impact of gas industry facilities are shown in Table 2. Ecosystem acidification risk (Ex(CL acid)) is typical for approximately 32% of Venezuela territory, eutrophication risk (Ex(CL eut.)) – for 45% of territory, risk of simultaneous increase of acidity and eutrophication (Ex(CL N)) – approximately for 9%. For majority of ecosystems where CL exceeding was detected the excess amounts to less than 100 e/ha per year. The ecosystems of equatorial forests on acid soils are the most “sensitive” to the acid compound of nitrogen fallout. Distrophic herb and herb-shrub biocenoses (including the ones used for pastures) are subject to the eutrophication risk, but one of the results of the increased inflow of nitrogen to these ecosystems will be the growth of their productivity, which can be regarded as positive changes.

<table>
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<tr>
<th>Ecosystem type</th>
<th>Percent of total area of certain ecosystem type</th>
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<tr>
<td></td>
<td>Ex(CL acid.)&gt;0</td>
</tr>
<tr>
<td>Forests</td>
<td>41.3</td>
</tr>
<tr>
<td>Shrub savannahs</td>
<td>22.7</td>
</tr>
<tr>
<td>Herb savannahs and pastures</td>
<td>14.7</td>
</tr>
<tr>
<td>Thinned out grassy-desert</td>
<td>23.3</td>
</tr>
<tr>
<td><strong>Total territory of the country</strong></td>
<td><strong>32.2</strong></td>
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The additional inflow of nitrogen to the ecosystems of Venezuela caused by NO\textsubscript{x} emission conditioned by the gas industry upgrade and increase in natural gas production, transportation and processing will result in insignificant growth of ecosystems with the potential risk of acidifying – on 0.02% of Venezuela territory (Table 3). Eutrophication risk that causes the changes in nutrition status of biogeocenoses and disorder in their biodiversity is sure to increase on 0.1% of country's territory.

\textbf{Table 3. The results of probabilistic risk assessment according to the data of 2006 (% of territory with the different levels of CL exceeding with no account/with account of NO\textsubscript{x} emission from gas industry facilities)}

<table>
<thead>
<tr>
<th>Risk classes, probability (%)</th>
<th>Percent of Venezuela territory</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Ex(CL acid.)&gt;0</td>
</tr>
<tr>
<td>Almost no risk (&lt; 5%)</td>
<td>80.47 / 80.36</td>
</tr>
<tr>
<td>Low risk level (5-25%)</td>
<td>10.53 / 10.63</td>
</tr>
<tr>
<td>Medium risk level (25-75%)</td>
<td>9.00 / 9.02</td>
</tr>
<tr>
<td>Increased risk level (75-95%)</td>
<td>0.0 / 0.0</td>
</tr>
<tr>
<td>High risk level (&gt; 95%)</td>
<td>0.0 / 0.0</td>
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\textbf{Conclusion}

The environmental risk assessments carried out for the regions of intensive gas production are pilot projects and evidently need revision. At the same time the proposed approaches allow to carry out the unified quantitative parametrisation and comparative analysis of risks associated with the impact of gas industry facilities on ecosystems in the areas of gas production, transportation and processing. On the regional scale, the described technology allows to identify and range the zone of probable impact of the different technological objects by their features and intensity of the caused environmental risks, which is necessary for risks monitoring and management.

\textbf{Literature}

10. Evaluation of impact on biota in the course of Bovanenkovo field development on Yamal Peninsula at the stage of feasibility study. IEJ UrO RAN. 2004
Abstract

Paper describes methodological approaches and case studies of quantitative assessment of environmental risks caused by the impact of gas industry facilities. The proposed technology is based on system analysis used together with the baselines of risk assessment and critical loads methodologies. The study is aimed at the development of methods to manage environmental risks in gas industry in order to provide medium-term and long-term environmental safety and sustainable development of the industry.